DRAFT
17 Mar 04

PROPOSED MRL/EMRL DEFINITIONS AND USE

MRL Development Working Group

DRAFT
17 Mar 04

Current Problem

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Support to our Warfighters is suffering as a result of Consistent problems with the DoD acquisition process.

- PMs lack sufficient knowledge of technologies, design and production.
- Results continue to include: cost increases; schedule delays; and production shortfalls.

GAO Report 1: Capturing Design & Manufacturing Knowledge Early Improves Acquisition Outcomes

Department of Defense ManTech

GAO-02-701, July 2002

Findings

Critical elements in successful new product development programs:

1. Requirements clearly defined / resourced
2. Product's design determined to be capable of meeting requirements
3. Reliable product can be produced repeatedly within established cost, schedule and quality targets

- Increased costs, delays, and degradation in performance / quality when products designed without early manufacturing consideration
- Timely manufacturing knowledge critical to program success
- Knowledge that design can be manufactured affordably and with consistent high quality prior to making a production decision ensures cost and schedule targets met

Recommendation: **SecDef improve DoD's acquisition process by incorporating best practices to capture and use manufacturing knowledge as a basis for decisions to commit to system production**

JDMTP Findings

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- Most Programs that “Fail” lack a Disciplined Systems Engineering Process.
- Programs that focus on manufacturing and production issues early-on have a far greater “success” rate.
- Mature Manufacturing Management Knowledge Base Exists; but Use is Sporadic and Not Standardized.
- Manufacturing Issues Not Adequately Addressed at All Milestone Reviews.

Industry Looks to DoD for Leadership

Factors Bearing

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- Acquisition Reform/Specs & STDs Reform
- Evolutionary Acquisition
- Rapid Transition of S&T
- Program Advocacy Versus Realism
- Diffused and Incomplete Knowledge Sets

Sustained Acquisition Excellence Requires: ility, Responsiveness, and Knowledge-Based Deci

Best Industry Practices

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- Looks at a broad spectrum of processes and performance before committing to expensive systems development and/or production
- Successful technology transition requires, at a minimum, an understanding of critical manufacturing processes
  - For some companies … a mature production capability
- Current TRL descriptions focus on evaluating prototype components within increasingly relevant environments to judge readiness for transition based upon performance demonstration
- Providing a manufacturing readiness level should move producibility concerns into earlier development phases
- Maturity of the manufacturing processes should to be evaluated continuously along the technology development path, else transition will be delayed or will not occur

GAO Report 2: Assessment of Major Weapon Systems

Department of Defense ManTech

Findings

GAO-03-476, May 2003

- Knowledge-based approach can lead to better acquisition outcomes:
  1. Resources and needs are matched
  2. The product design is stable
  3. *Production processes are mature*
- Reviewed 26 defense programs. Example findings:
  - F/A-18E/F: Labor efficiency rates have steadily improved & aircraft delivered ahead of schedule because design & mfg knowledge attained early on
  - F/A-22: In Sept 2001, AF acknowledged production cost increase of ~$5.4 billion over congressional cost limit because of delays in design & production knowledge.
  - JASSM: Contractor will produce first LRIP lot on schedule because design was stable at critical points in development and production processes were demonstrated; However, key production processes that have cost implications will have to be addressed prior to FRP in order to achieve FRP capacity

Recommendation: **Establish cost, schedule and quality targets for product manufacturing early on in order to obtain process maturity**

F/A-18E/F Super Hornet

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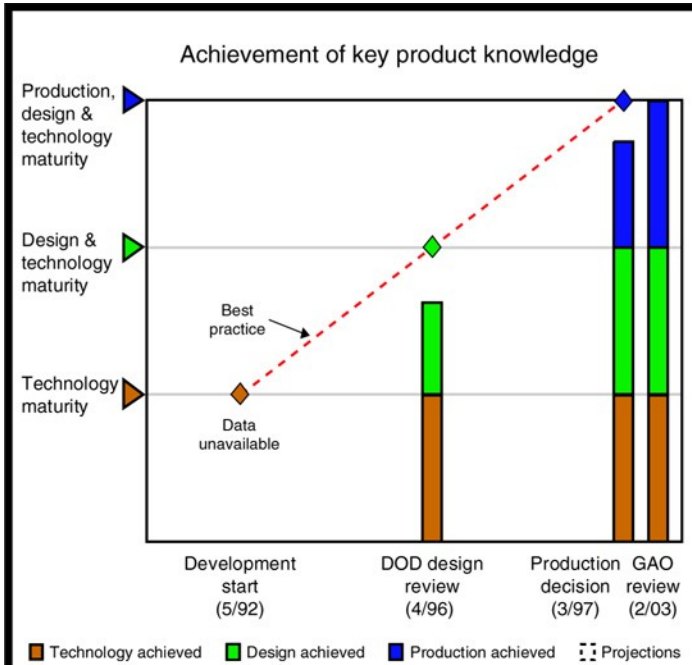
GAO-03-476, May 2003

Source: U.S. Navy.



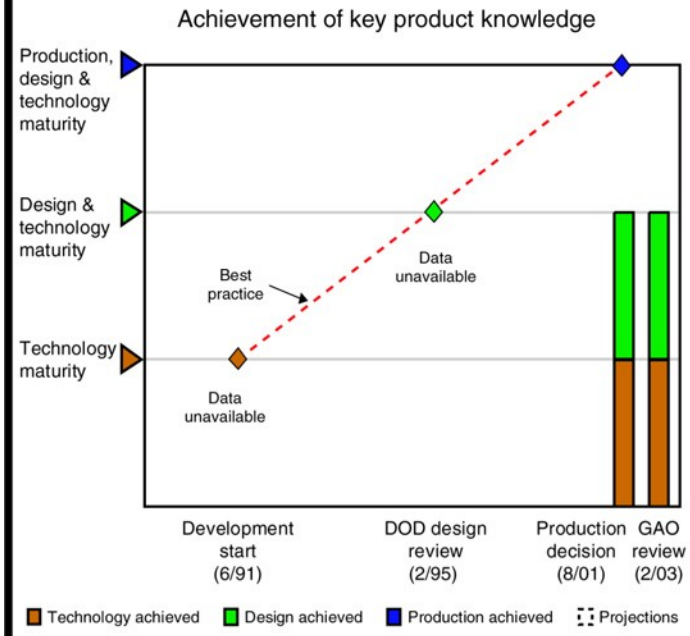
The F/A-18E/F went into full-rate production in June 2000. Although the program proceeded without obtaining full product knowledge at key decision points, it embraced the concepts of attaining design and manufacturing knowledge early in development. The program released just over half of its engineering drawings by its design review. When low-rate production began, nearly all of the drawings were released and about 75 percent of the manufacturing processes were in control. The Navy reduced some program risk because aviation electronics from an earlier version of the F/A-18 were incorporated into the baseline F/A-18E/F. Furthermore, focus was placed on commonality between the F/A-18 C/D and the F/A-18 E/F, which further reduced risk.

F/A-22 Raptor

Department of Defense ManTech

GAO-03-476, May 2003

Source: F/A-22 System Program Office.



Because the F/A-22 Program Office stopped collecting process control data in 2000, the program began production in 2001 with no proof that processes were in control, as defined by best practice standards. Technology appears mature and the design appears stable; however, problems with the vertical tail and the avionics have been discovered recently, which require design modifications. Delays in capturing technology, design, and production knowledge and these latest problems contributed to cost increases and schedule delays. The potential exists for further cost increases and schedule delays as a significant amount of the test program remains, including operational tests. Also, the latest production cost estimate is likely to increase because of several factors, and the estimate assumes over $25 billion in offsets from cost reduction plans.

JASSM

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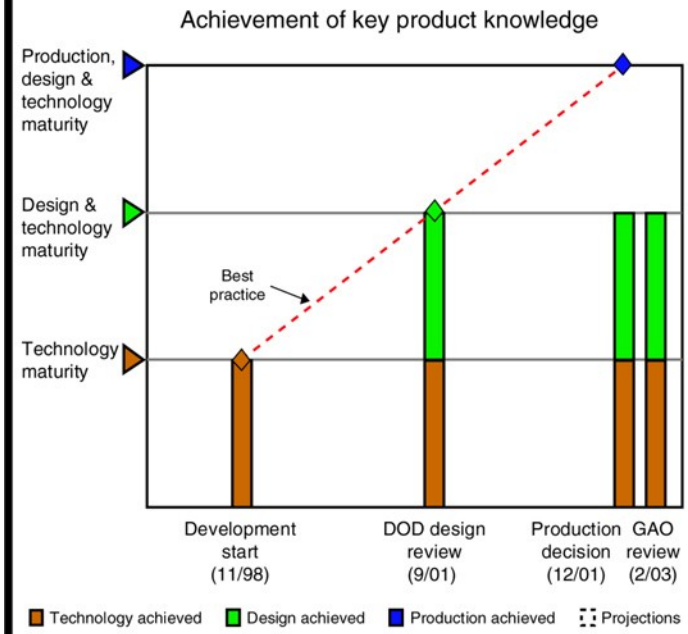
GAO-03-476, May 2003

Source: JASSM Program Office.



The JASSM program entered production in December 2001 without ensuring that production processes were in control, according to best practice standards. However, program officials indicated that they have demonstrated the production processes and that they sample statistical data at the subsystem level. The program ensured that the technology was mature and that the design was stable at critical points in development, closely tracking best practice standards. Redesign remains one area of concern because recent test failures have led to the delay of operational tests. The program has identified fixes to the problems, and a retrofit plan is in progress. The contractor's ability to attain a higher production rate is another area of concern.

Joint Common Missile

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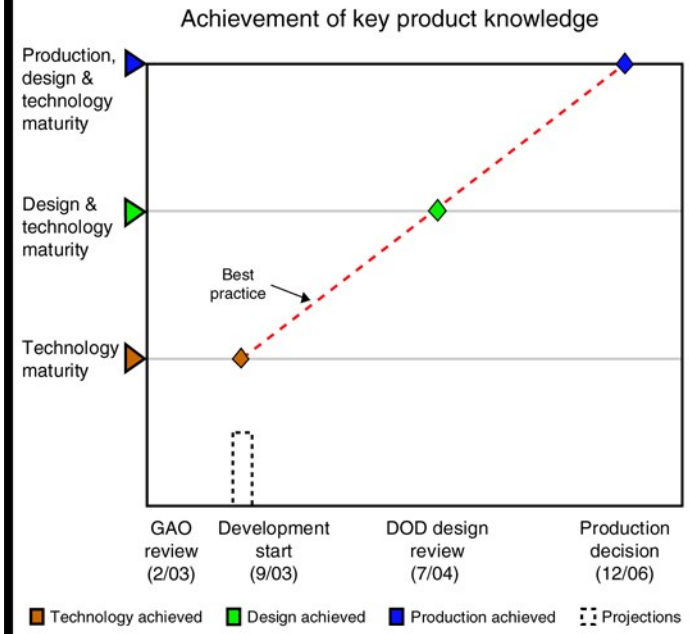
GAO-03-476, May 2003

Source: U.S. Army.



The Joint Common Missile is scheduled to enter product development before any of its critical technologies are fully mature, according to best practices. Furthermore, program officials currently project that the critical technologies will not reach maturity until a year after the design review. The Army will initially focus development on an air-launched version.

Technology Opportunities to Warfighter Needs

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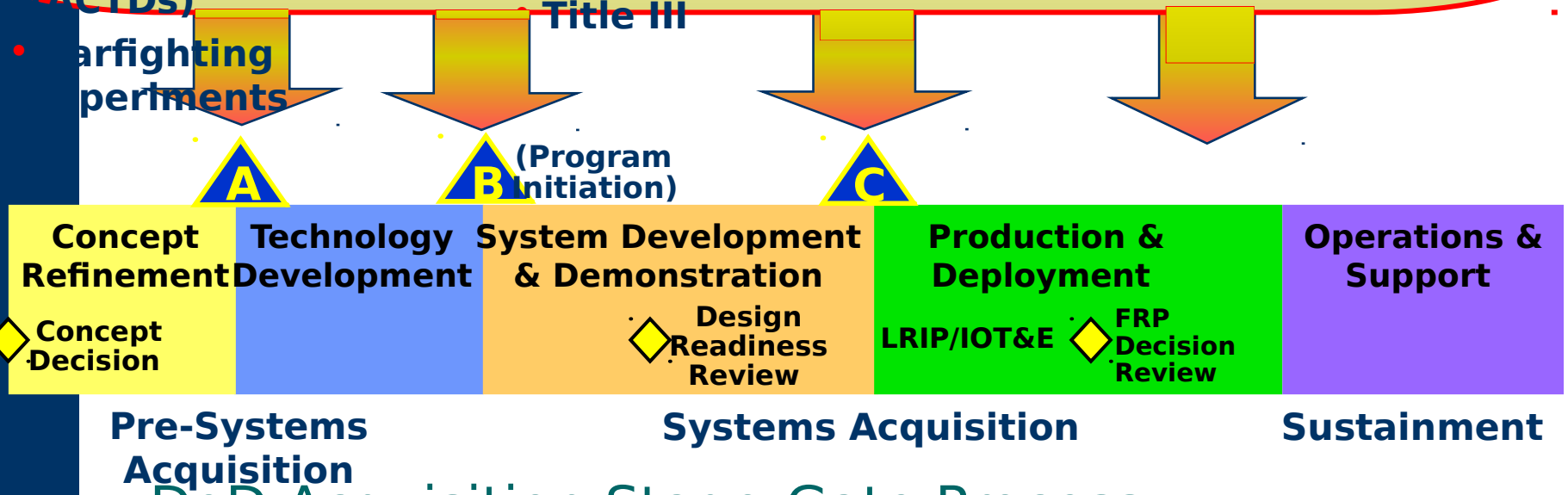
Core S&T Transition

- Advanced Technology Demonstrations (ATDs)
- Advanced Concept Technology Demonstrations (ACTDs)
- arfighting periments

Enabling S&T Transition

- S&T Affordability Initiative
- Dual-Use S&T
- **ManTech**
- Defense Product Act
- Title III
- Small Business Innovative Research
- Independent Research & Development
- Technology Transfer Activities



DoD Acquisition Stage-Gate Process

The Defense Acquisition Management Framework

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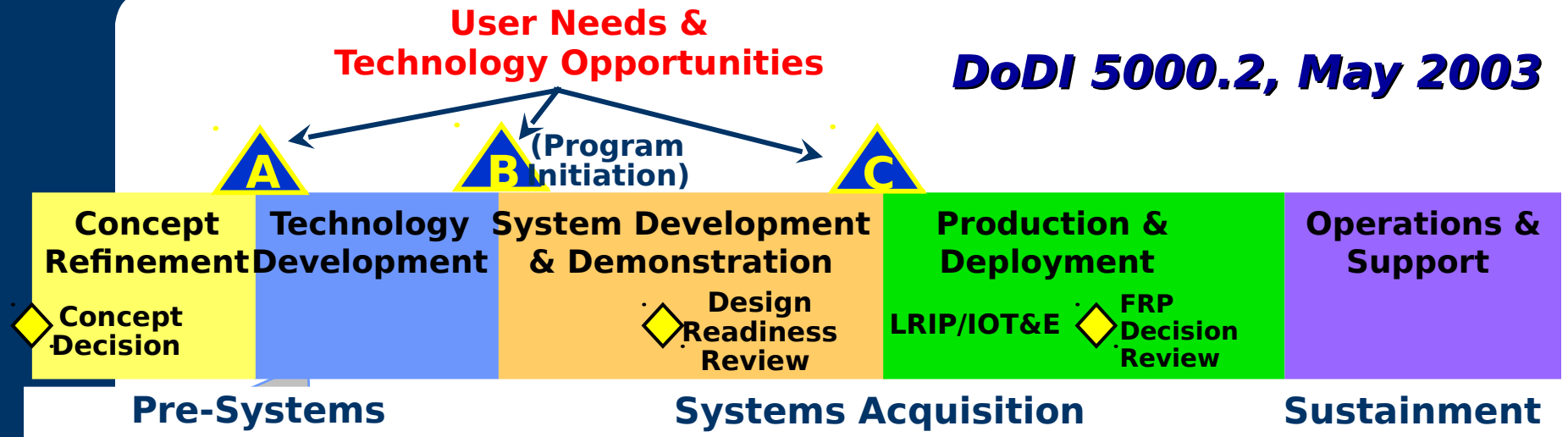

- **Purpose**: Reduce Technology RISK; determine critical enabling technologies to be integrated into a full system
- **Entrance Criteria**: MDA approved Technology Development Strategy
- **Exit Criteria**: Affordable increment of militarily useful capability
  - Technology State: proven in a relevant environment
  - Timeframe: developed, produced and fielded within a short time

Need for early MRL assessment:

- Producibility & identification of manufacturing processes not required until SDD
  - IPPD: Successful products require the capture of design AND mfg. knowledge early in product development (i.e., Tech Development)
- Current policy does not require capture of design & mfg. knowledge, criteria or metrics to enter SDD (Milestone B)
  - Consider mfg. & producibility assessments in in Technology Development Phase

DoD Instruction 5000.2 – Operation of the Defense Acquisition System

5000 Model - Manufacturing & Transition Related Inputs

	Concept Refinement	Technology Development	System Devel. & Demonstration	Production & Deployment	Operations & Support
	Concept Decision		Design Readiness Review	LRIP IOT&E; FRP Decision Review	
	A		B	C	
Purpose	Refine initial concept & develop a Technology Development Strategy	Reduce Technology Risk and Determine set of technologies to be integrated into a full system	Develop system, reduce integration & mfg risk, ensure operational support; conduct design for producibility	Achieve operational capability that satisfies mission need	Meet operational support requirements & satisfy life-cycle cost objectives
Criteria	• Assessment of critical technologies including tech. maturity & risk • Identify COTS functionality & solutions from large & small businesses • No specific requirement for mfg or pr… a…	▪ Assessment of viability of technologies concurrent with user requirements ▪ Exit Criteria: When an affordable increment of military useful capability is identified & …	• Updated or new technology maturity assessment • Maximum use of commercial technology • Include "design for producibility" and simulation based acquisition • *Identify critical manufacturing proces…*	• Implement acceptable developmental & operational testing • Ensure no *significant* mfg. risks. Process is in control • No discussion of technology assessment	• Optimize operational readiness through embedded diagnostics & technology refreshment • Revise sustainment strategies to meet updated performance … …ments

Current Problem | AS&C Opportunity | DMTP Approach | Recommendations

DoD Instruction 5000.2 – Operation of the Defense Acquisition System

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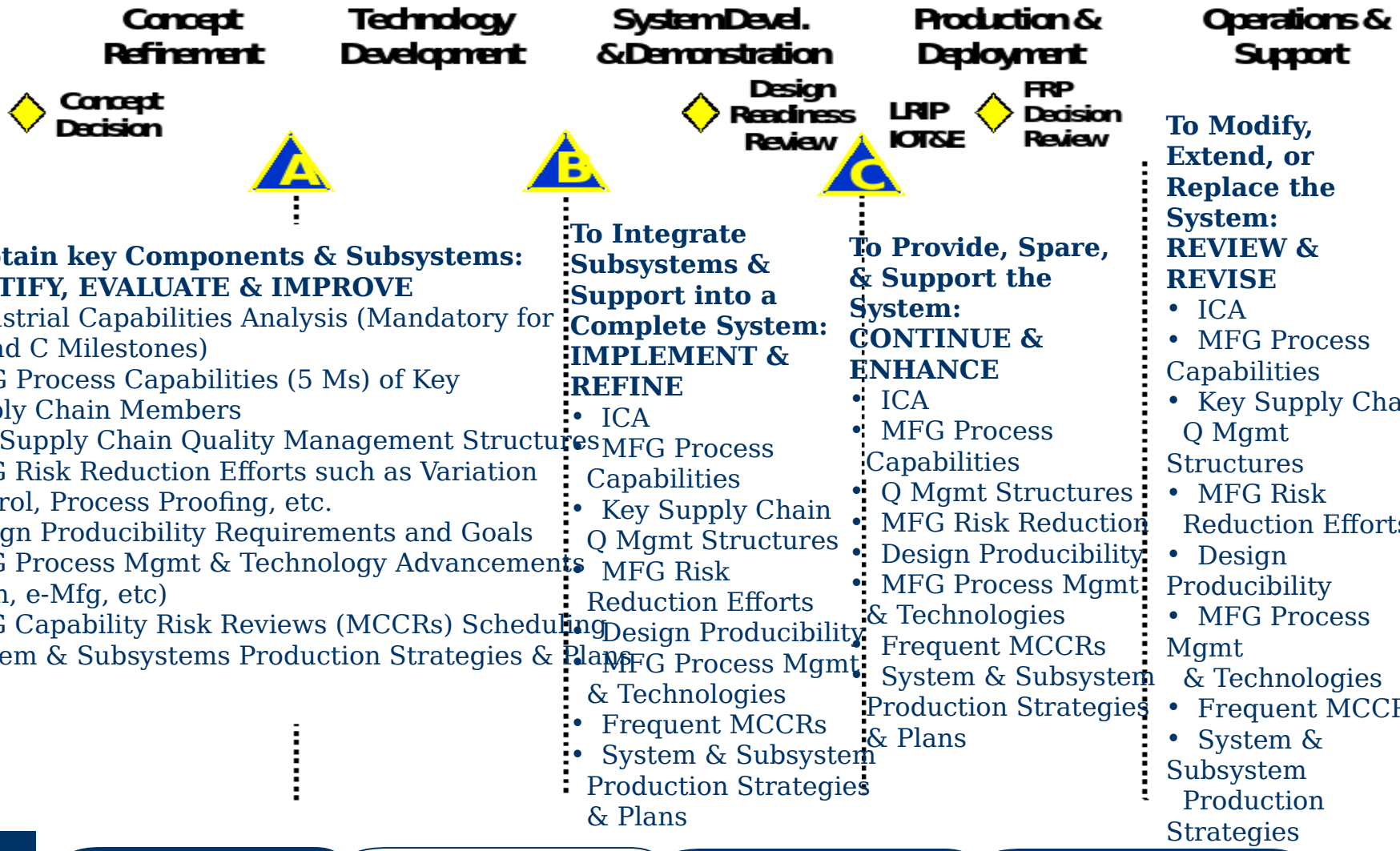
12 May 2003

5000 Model - Manufacturing & Transition Related Inputs


Concept Refinement
Technology Development
System Devel. & Demonstration
Production & Deployment
Operations & Support
Concept Decision
A
B
Design Readiness Review
LRIP IOT&E
C
FRP Decision Review
btain key Components & Subsystems:
NTIFY, EVALUATE & IMPROVE
ustrial Capabilities Analysis (Mandatory for nd C Milestones)
G Process Capabilities (5 Ms) of Key pply Chain Members
Supply Chain Quality Management Structures
G Risk Reduction Efforts such as Variation trol, Process Proofing, etc.
sign Producibility Requirements and Goals
G Process Mgmt & Technology Advancements an, e-Mfg, etc)
G Capability Risk Reviews (MCCRs) Scheduling
stem & Subsystems Production Strategies & Plans
To Integrate Subsystems & Support into a Complete System:
IMPLEMENT & REFINE
• ICA
• MFG Process Capabilities
• Key Supply Chain Q Mgmt Structures
• MFG Risk Reduction Efforts
• Design Producibility
• MFG Process Mgmt & Technologies
• Frequent MCCRs
• System & Subsystem Production Strategies & Plans
To Provide, Spare, & Support the System:
CONTINUE & ENHANCE
• ICA
• MFG Process Capabilities
• Q Mgmt Structures
• MFG Risk Reduction
• Design Producibility
• MFG Process Mgmt & Technologies
• Frequent MCCRs
• System & Subsystem Production Strategies & Plans
To Modify, Extend, or Replace the System:
REVIEW & REVISE
• ICA
• MFG Process Capabilities
• Key Supply Chain Q Mgmt Structures
• MFG Risk Reduction Efforts
• Design Producibility
• MFG Process Mgmt & Technologies
• Frequent MCCRs
• System & Subsystem Production Strategies

Doctrinal Manufacturing Risk Reduction Activities

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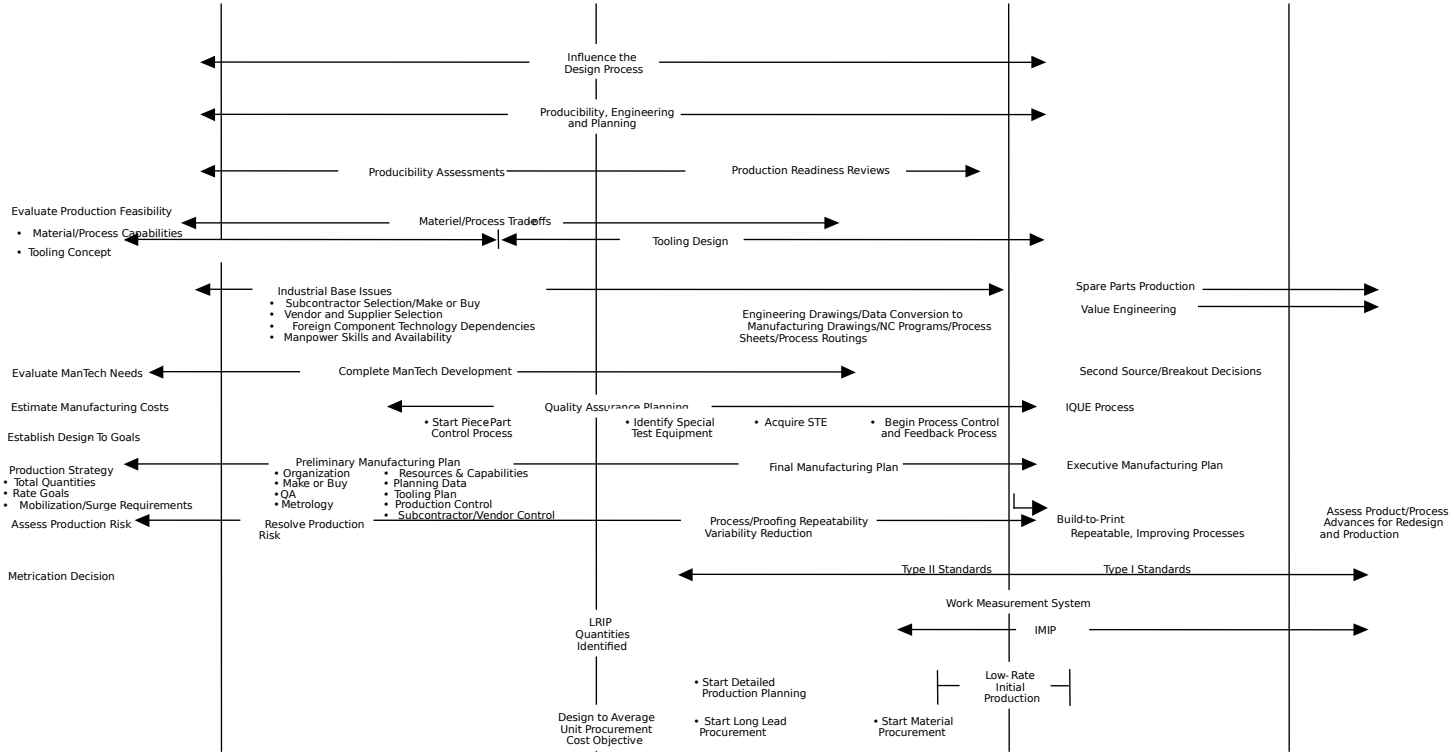
Manufacturing Management



ManTech Experience

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- ***Recent Case histories:***
  - ***Joint Strike Fighter Technology Readiness Assessment***
  - ***"Routine": Body Armor***
  - ***Revolutionary Tech: Metals Affordability Initiative(MAI)***
  - ***Warfighter Generated: Advanced Concept Technology Demonstrators(ACTD)***
  - ***Battery Manufacturing (BATTMAN) Study***

Vision

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Develop and institutionalize a set of Manufacturing Readiness Levels (MRLs).

- Consistent with Current DoD 5000 Acquisition Doctrine, Practice, and Milestone Decision Points,
- Reconciled With TRLs,
- Reconcilable With MDAs EMRLs,
- Constructed in the form of Guidance versus "Prescriptive",
- Aligned with Evolving NASA TRL/MRL Evolution,
- Potentially Capable of Serving as the basis for a wider

wer Acquisition Teams with Product Knowledge at Key Po

Statutory Requirement (10 USC 2440)

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- DoDI 5000.2 Industrial Capabilities
  - Part of Acquisition Strategy
  - Required at MS B and C

- DFARS 207.105(b)(19) Contents of Written Acquisition Plans

  (A) An analysis of the capabilities of the national technology and industrial base to develop, produce, maintain, and support such program, including consideration of ...

  (1) The availability of essential raw materials, special alloys, composite materials, components, tooling, and production test equipment for the sustained production of systems fully capable of meeting performance objectives established for those systems; the uninterrupted maintenance and repair of such systems; and the sustained operation of such systems.

  (2) Consideration of requirements for efficient manufacture during the design and production of the systems to be procured under the program.

  (3) The use of advanced manufacturing technology, processes, and systems during the research and development phase and the production phase of the program ...

AKSS

Mfg. Readiness Levels (MRLs)

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Why MRLs?

- Current Technology Readiness Level (TRL) approach does not require prototype components to be producible, reliable, or affordable
- Successful products require the capture of design and manufacturing knowledge early in product development
- MRLs provide a more complete evaluation of a system by addressing producibility earlier in development

What are MRLs?

- **Evaluates "manufacturing readiness" of product**
- **Supplements existing TRLs**
- **Used to assess maturity of a technology's underlying manufacturing processes**
  - **Enable rapid, affordable transition to**

TRLs & Draft MRLs (Summary Level)

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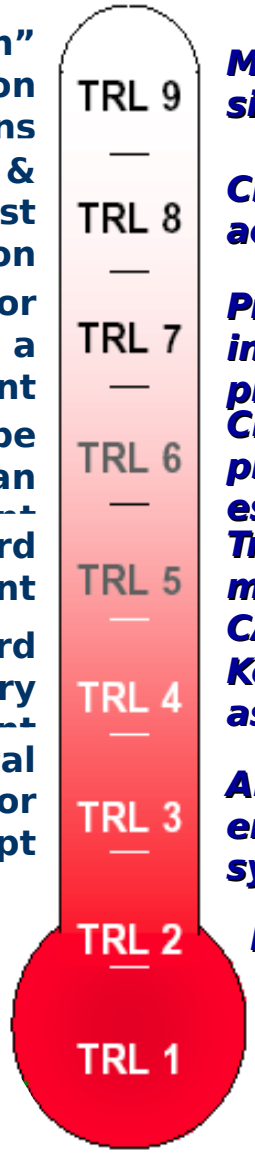

Actual system "flight proven" through successful mission operations	TRL 9	***Manufacturing processes are operating at six-sigma or appropriate quality level***
Actual system completed & "flight qualified" through test & demonstration	TRL 8	***Critical mfg. processes demonstrate acceptable yield for pilot line or LRIP***
System/subsystem model or prototype demonstration in a relevant environment	TRL 7	***Prototype system built on soft tooling, initial sigma levels established for critical processes***
System prototype demonstration in an operational environment	TRL 6	***Critical manufacturing processes prototyped, targets for improved yield established***
Component and/or breadboard validation in relevant	TRL 5	***Trade studies & lab experiments define key mfg. processes & sigma levels needed to meet CAIV targets***
Component and/or breadboard validation in laboratory environment	TRL 4	***Key manufacturing processes identified & assessed in lab. CAIV targets established***
Analytical & experimental critical function & /or characteristic proof-of-concept	TRL 3	***Analyses identify manufacturing concepts or emerging producibility issues for breadboard system***
Technology concept and/or application formulated	TRL 2	***N/A***
Basic principles observed and reported	TRL 1	***N/A***

CAIV: Cost As An Independent Variable

TRLs & Draft MRLs (Detailed Discussion)

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TRL	Definition	Description	Supporting Information
1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties. MRL N/A	Published research that identifies the principles that underlie this technology. References to who, where, when.
2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies. MRL N/A	Publications or other references that outline the application being considered and that provide analysis to support the concept.
3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development (R&D) is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Analyses identify manufacturing concepts or emerging producibility issues for breadboard system.	Results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. References to who, where, and when these tests and comparisons were performed.
4	Component and/or breadboard validations in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in the laboratory. Key manufacturing processes identified & assessed in lab. Cost as an Independent Variable (CAIV) targets established.	System concepts that have been considered and results from testing laboratory-scale breadboards(s). References to who did this work and when. Provide an estimate of how breadboard hardware and test results differ from the expected system goals.
5	Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components. Trade studies and lab experiments define key manufacturing processes and sigma levels needed to meet CAIV targets.	Results from testing a lab breadboard system are integrated with other supporting elements in a simulated operational environment. How does the "relevant environment" differ from the expected operational environment? How do the test results compare with expectations? Was the breadboard system refined to more nearly match expected system goals?

TRLs & Draft MRLs (Detailed Discussion – Cont'd)

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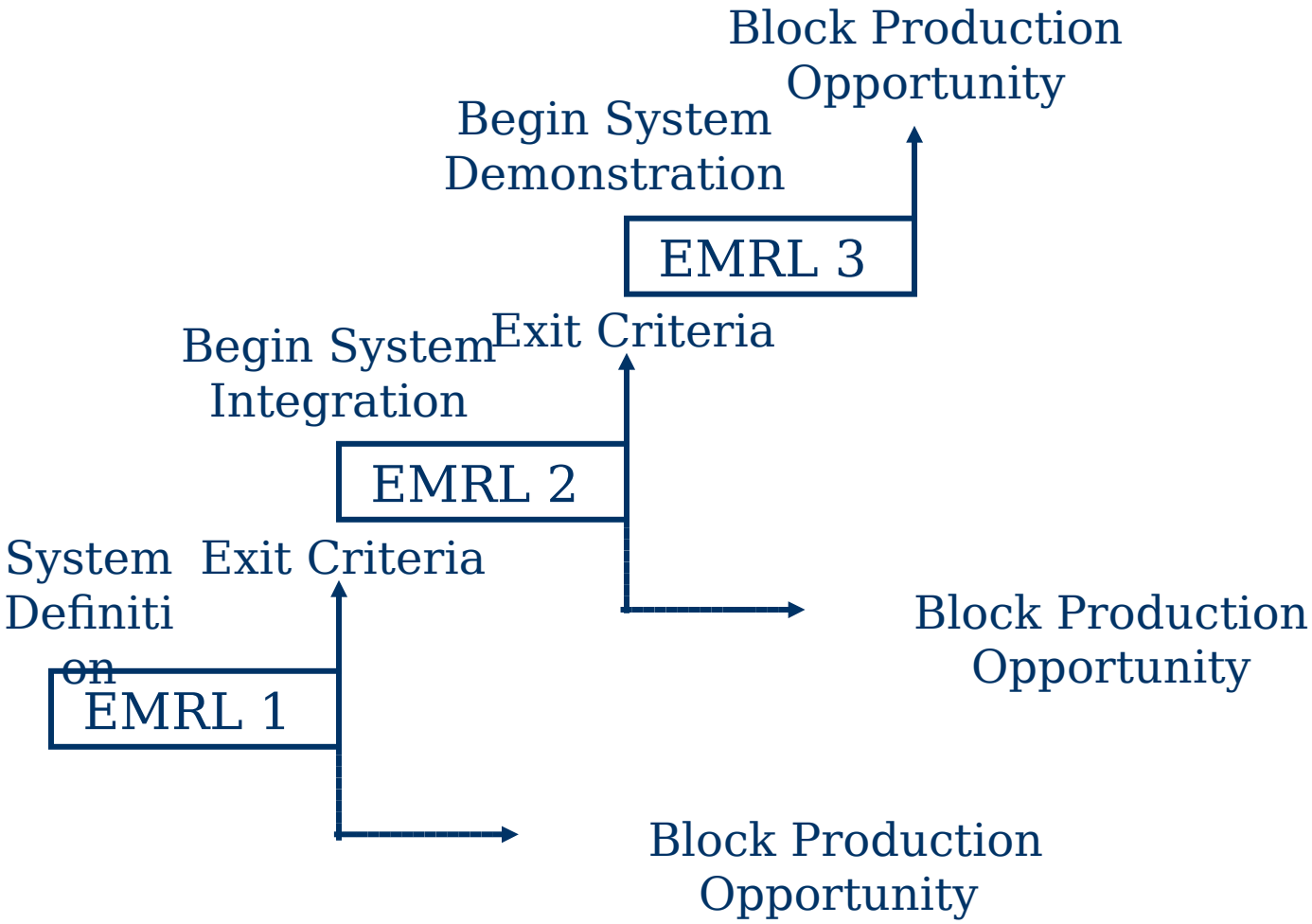
TRL	Definition	Description	Supporting Information
6	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment. Critical manufacturing processes prototyped, targets for improved yield established.	Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems encountered before moving to the next level?
7	System prototype demonstration in an operational environment	Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft. Prototype system built on soft tooling, initial sigma levels established for critical manufacturing processes.	Results from testing a prototype system in an operational environment. Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options or actions to resolve problems encountered before moving to the next level?
8	Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications. Critical manufacturing processes demonstrate acceptable yield for pilot line or LRIP.	Results of testing the system in its final configuration under the expected range of environmental conditions in which it will be expected to operate. Assessment of whether it will meet its operational requirements. What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems encountered before finalizing the design?
9	Actual system proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions. Manufacturing processes are operating at six-sigma or	Operational Test and Evaluation (OT&E) reports.

What are Engineering & Manufacturing Readiness Levels (EMRL)

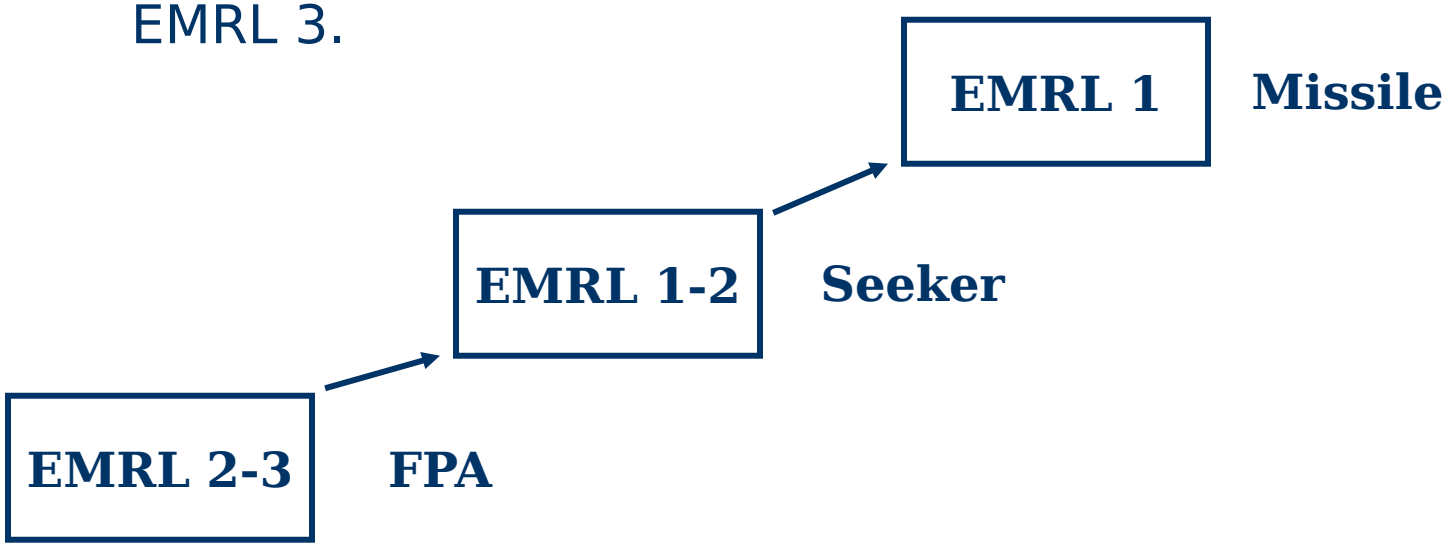
- EMRLs provide the framework with specific criteria and metrics to capture the design and manufacturing knowledge for System Integration and Demonstration and identification of Block Production Opportunities
- EMRL Criteria Metrics are based on sound System Engineering Principles and are to be used by Program Managers to assess product maturity and identify potential program risk areas.
- The exit criteria and metrics for each EMRL indicate the level of maturity for entry into the next development phase, or product maturity level for a Block Production Opportunity

EMRLs and Development Phases



EMRLs and WBS

- EMRLs can be tailored to apply at the Item, Assembly, Sub-component, Component, and Element levels
- Each lower WBS product should be at a higher level EMRL (level of maturity) than the higher level product, i.e., if the missile has met the exit criteria for EMRL 1, the seeker should have met the exit criteria for EMRL 2 and the focal plane should have met the exit criteria for EMRL 3.



What do EMRLs give to Program Managers?

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- Engineer & Manufacturing Readiness Levels (EMRL) provide
  - Criteria to Explicitly Measure “Product” Maturity
  - Inclusive of Technology Readiness Levels
  - Adds Design, Manufacturing, Producibility, and Quality Measures
- EMRL Criteria Utility
  - Mandates sound System/Design Engineering with focus on Manufacturing, Producibility, Quality, Affordability and Test
  - Mandates disciplined process with specific criteria and metrics
    - Assessment process requires documented proof that Exit Criteria have been met
  - Mechanism to collect Critical Program Knowledge throughout the Development Process
  - Provides Standardized Program Reporting Vehicle to Senior Management on Capability Maturity across BMDS Programs

EMRL DEFINITION

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EMRL 1 - Component, Subcomponent, Assembly or Item validation in laboratory environment or initial relevant engineering application/bread board, brass board development.

This is the lowest level of production readiness. Technologies must have matured to at least TRL 4. At this point all systems engineering requirements have not been validated and there are significant systems engineering/design changes. Component physical and functional interfaces have not been defined. Materials, machines and tooling have been demonstrated in a laboratory environment, but most manufacturing processes and procedures are in development. Inspection and test equipment have been demonstrated in a laboratory environment, but overall quality and reliability levels and key characteristics have not yet been identified or established.

EMRL 2 -Component, Subcomponent, Assembly or Item in prototype demonstration beyond breadboard, brass board development.

During the prototype demonstration phase systems engineering requirements are validated and defined. However, many systems engineering/design changes and physical and functional interfaces are still not yet fully defined. Technologies must have matured to at least TRL 6. Materials are initially demonstrated in production and manufacturing processes and procedures are initially demonstrated. At this point there are likely major investments required for machines and tooling. Inspection and test equipment should complete development and be tested in a manufacturing environment. Quality and reliability levels and key characteristics should be initially identified.

EMRL 3 - Element, Component, Subcomponent, Assembly or Item in advanced development. Ready for low rate initial production.

During the advanced development phase prototypes should mature to at or near planned system engineering required performance levels for an operational system. Technologies must have matured to at least TRL 8. At this point systems engineering/design changes should decrease significantly. Physical and functional interfaces should be clearly defined. All materials are in production and readily available. Manufacturing processes and procedures should be well understood, under control and ready for low rate initial production. Only moderate investments in machines/tooling should be required at this time. Machines and tooling should be demonstrated in a production environment. All quality and reliability requirements and key characteristics should be identified though not necessarily fully capable or in control.